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Entropy of extremal black holes: Horizon limits through charged thin shells in a unified approach

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Abstract

© 2016 American Physical Society.Using a unified approach, we study the entropy of extremal black holes through the entropy of an electrically charged thin shell. We encounter three cases in which a shell can be taken to its own gravitational or horizon radius and become an extremal spacetime. In case 1, we use a nonextremal shell, calculate all the thermodynamic quantities including the entropy, take it to the horizon radius, and then take the extremal limit. In case 2, we take the extremal limit and the horizon radius limit simultaneously; i.e., as the shell approaches its horizon radius, it also approaches extremality. In case 3, we take first an extremal shell, and then take its horizon radius. We find that the thermodynamic quantities, in general, have different expressions in the three different cases. The entropy is the Bekenstein-Hawking entropy S=A+/4 (where A+ is the horizon area) in cases 1 and 2, and in case 3 it can be any well-behaved function of A+. The contributions from the various thermodynamic quantities for the entropy in all three cases are distinct. Indeed, in cases 1 and 2, the limits agree in what concerns the entropy but they disagree in the behavior of all other thermodynamic quantities. Cases 2 and 3 disagree in what concerns the entropy but agree in the behavior of the local temperature and electric potential. Case 2 is, in a sense, intermediate between cases 1 and 3. Our approach sheds light on the extremal black hole entropy issue.

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